HYDROLOGIC TRANSPORT OF *ESCHERICHIA COLI* THROUGH A PIEDMONT WATERSHED

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Abstract: The United States Environmental Protection Agency has published a Final Rule establishing *Escherichia coli* (*E. coli*)-based water quality standards for the protection of public health. To date, thirteen states have transitioned at least partially to the new voluntary *E. coli* standard. The State of Georgia, with 4263 kilometers of impaired waterways, currently uses fecal coliform indices to gauge impairment of water resources; however, this method has been widely criticized as inadequate for providing the maximum amount of public protection against water-borne pathogens. As water resource management evolves to operate at the watershed scale, increasing stakeholder concerns over eutrophication and potential increases in pathogenic bacteria densities complicate alternative management futures. Efforts to describe the transport of bacteria from areas of non-point source pollution to receiving bodies of water are common; however, no explanation of *E. coli* transport and fate in Southeastern watersheds exists. Specific research goals focused on the hydrologic transport of *E. coli* from stormwater discharge, an animal confinement operation, and through a small subwatershed and pond. Initial results to quantify and characterize the source, transport mechanism, and fate of *E. coli* at the watershed scale are discussed. A modern toolbox approach to bacteria source tracking is proposed and a theoretical model constructed to aid in the development of accurate and comprehensive Total Maximum Daily Loads (TMDLs) for the State of Georgia.

INTRODUCTION AND PROBLEM STATEMENT

The United States Environmental Protection Agency (USEPA) has published a Final Rule establishing *Escherichia coli* (*E. coli*)-based water quality standards for the protection of public health (USEPA 1986, 1996). However, the State of Georgia currently uses fecal coliform indices to gauge impairment of water resources. Stakeholder concerns over eutrophication and potential increases in pathogenic bacteria densities further complicate this disparity. Efforts to quantify *E. coli* in areas of point and nonpoint source pollution are common, but a comprehensive explanation of *E. coli* transport and fate in southeastern waters does not exist. While numerous studies have been published detailing fecal indicator bacteria in southeastern surface waters, limited information is available on the affect of temperature, light, pH, dissolved oxygen, nutrients, and hydrology on *E. coli* in Southeastern Piedmont landscapes (Francy et al. 2000, 1993).

This report examines the hydrologic transport and fate of *E. coli* from stormwater flow and an animal confining operation, through a small subwatershed and into a pond. Results are used to quantify and characterize the source, transport mechanism, and fate of *E. coli* in an impounded ecosystem. Insights from this study will be used to understand similar processes occurring in other temperate watersheds, namely the Upper Chattahoochee River Basin (UCRB), in support of the State of Georgia's transition to the new USEPA *E. coli* standard and the development of accurate and comprehensive TMDLs.

High levels of fecal-indicator bacteria in rivers, streams, and impounded bodies of water may indicate the possible presence of pathogenic microorganisms. Cholera, typhoid fever, bacterial dysentery, infectious hepatitis, and cryptosporidiosis are some well known waterborne diseases which spread through water contaminated with fecal matter. Other major ailments transmitted by polluted water include Reo-, adeno-, and enteroviruses; coxsackievirus and poliovirus. Ear, eye, nose, and throat infections also can result from contact with contaminated water. Contamination sources include municipal wastewater discharges; leachate from domestic septic systems; runoff or ground-water seepage from livestock areas, such as pastures; concentrated animal feeding operations (CAFOs), or areas where manure is applied as fertilizer; or from wildlife populations.

In addition to the direct public-health concerns associated with fecal contamination, fecal coliform bacteria are also commonly used for determining water quality because they have survival rates in aquatic systems similar to other potentially more dangerous fecal-borne pathogens such as *Salmonella* spp. and *Shigella* spp. Bacterial populations in freshwater systems are generally higher along riverbanks and lake shores (Gurijala and Alexander 1990). This is due to higher concentrations of nutrients from land runoff, sewage and industrial discharges, and vertical mixing. The combined effects of these forces increase the total nutrients within aquatic systems and can increase the life spans of normally short-lived bacterial inhabitants, possibly increasing the risk to human health. Furthermore, it has been shown that fecal coliforms can survive significantly longer in water laden with sediment than in those lacking sediment. These factors hold many implications for the increased survival of coliform bacteria (fecal coliform and *E. coli*) in polluted systems.

Nationwide, the fate and transport of coliform bacteria in impounded waters has been reported for some rivers, streams, and large reservoirs (Wilhelm and Maluk 1998; Francy et al. 1993). In Georgia, rapid urbanization of the UCRB above Lake Sidney Lanier has increased nutrient and bacteria inputs to this storage reservoir that provides drinking water and recreation to over 3 million people. The threat of increased eutrophication of Lake Lanier and other receiving bodies downstream of the UCRB has stimulated researchers and the general public to become more proactive in efforts to identify and reduce inputs to the lake by bacteria source tracking (BST), improved Best Management Practices (BMPs) and innovative watershed design (Dombek et al. 2000; Parveen et al. 1999; Hagedorn et al. 1999).

A suggested management alternative would be the placement or redesign of low-cost impoundments in low-order headwater streams to ameliorate the effects of coliform bacteria on public health. Water quality improvements of such structures on receiving bodies has been known for decades, but has not been widely reported in the scientific literature. A definitive study on the effect in the Southeastern Piedmont of small impoundments on the fate and transport of fecal coliform and *Escherichia coli (E. coli)* bacteria would help to demonstrate the utility of these structures as an alternative watershed management technique.

MATERIALS AND METHODS

The project objectives include a) the investigation of the methodology of ribotyping *Escherichia coli* bacteria to a known source under controlled conditions at the watershed scale, b) the determination of the source and primary mechanism of bacteria transport from the terrestrial environment to the aquatic environment, c) the determination of the influence of southeastern Piedmont impoundments on the transport and fate of *Escherichia coli*, d) the evaluation of the abiotic factors of temperature, pH, dissolved oxygen, solar irradiation, nutrients, and hydrologic flow against *E. coli* densities, e) providing scientific data from these experiments to concerned parties to facilitate development of Total Maximum Daily Load (TMDL) standards for *E. coli* bacteria in Georgia, and f) proposing management alternatives to reduce *E. coli* densities, with insight to changes in hydrologic flow conditions.

Study Area

The Catfish Pond is a 0.71 ha (7124 m^2) impoundment contained within a 12.9 ha (32.2 ac) subwatershed in Whitehall Experimental Forest, near the campus of the University of Georgia, Athens, Georgia, USA, (83° 24'W, 33° 54'N). Whitehall Forest is classified warm temperate with average annual ambient air temperature and precipitation averaging 17°C and 1252 mm, respectively. The Catfish Pond is situated downslope of research timber plots and an animal confinement operation (deer pen, N = 110) of the experimental forest, directly adjacent to the Oconee River, with all surface flow supplied by a first order perennial stream. During 1998 the pond was artificially enriched to study the effects of eutrophication at the ecosystem scale. Construction of a new laboratory facility atop the watershed divide began in August 2000.

Sampling was conducted between June 12 and October 20, 2000, at the Catfish Pond and throughout its 12.9 ha subwatershed. To monitor how the watershed responded to precipitation, four water level transducers, two hydraulic flumes, a tipping bucket, solar panels, and four Campbell CR-10 dataloggers were installed to record rainfall and stage level in the stream and pond. Based on previous sampling efforts (1998 - 1999) a significant rain event for the Whitehall watershed was established at ≥ 30mm (1.2") precipitation in 24 hours. Five significant events were intensively sampled for coliform and *E. coli* densities at the pond, Whitehall deerpens, and 10 deadfall samplers (5 control, 5 test sites) throughout the subwatershed.

The Catfish Pond and its headwater stream were sampled 3 – 4 times per week during the course of this study. Using 500ml sterilized nalgene bottles, water samples were collected along 15 (20m x 20m) transects, and at three 0.5m depth intervals in the pond. Total coliforms and *E. coli* were measured using the QuantiTray technique with Colilert media (APHA 2000 and manufacturer's instructions).

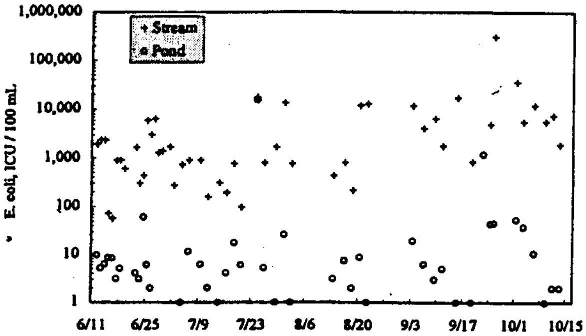

Figure 1. Coliform concentrations within and upstream of the Catfish Pond at Whitehall Forest.

RESULTS

Emphasis is placed on coliform data analyses because Georgia uses fecal coliform as an indicator bacterium for freshwater standards. Total coliform concentrations in the Whitehall study area ranged from less than 1 to over 2,400,000 col/100 mL (Figure 1). Virtually every stream sample analyzed exceeded the Georgia total coliform standard of 200 col/100 mL (May – October). The highest single total coliform concentrations were observed during the passing of Tropical Storm Helene (2,496,000 col/100mL) and the 125 mm of precipitation in 72 hours that mobilized accumulated fecal material and associated bacteria.

Statistically significant correlations between fecal-indicator bacteria concentrations and selected water quality constituents varied temporally and spatially. Data analysis is ongoing, however, preliminary results indicate streamflow, water temperature, pH, turbidity, nitrate, ammonia, organic nitrogen, total phosphorus, organic carbon, and dissolved oxygen were significantly correlated with some concentrations. Significant correlations ($\alpha = 0.05$) of some fecal-indicator bacteria with at least one water quality constituent were observed at all stations except the Catfish Pond tailwater (drought, no flow).

DISCUSSION

Bacteria data from direct sampling of storm flows confirm the chemical argument that surface flows are responsible for bacteria contamination. The reduced costs of the defined substrate method permitted a larger sample size, allowing complete watershed sampling coverage during significant rain events. While elevated levels of total coliforms and *E. coli* were observed from the stormwater discharge outlets atop the watershed divide, these signals were eclipsed by readings from the Whitehall CAFO. All readings were strongly correlated with increased turbidity and exhibited a slight lag when plotted with the storm hydrograph.

Shortly after the hydrograph peak, a flip-flop occurred in bacteria densities in the stream and pond. Decreased bacteria loading in the stream was inversely correlated with increased loading in the pond. After storm cessation, high bacteria densities persisted in the Catfish Pond for three to six days, depending on precipitation duration and intensity. Overall, the pond exhibited an ameliorating effect on total coliform and *E. coli* densities, responding as a natural (though man-made) ecosystem filter.

Bacteria contamination can originate from point or nonpoint sources. The presence or absence of certain bacteria can provide clues about the origin of contamination. *E. coli* inhabit the intestinal tract of warm-blooded animals and their presence in water is a direct indication of fecal contamination. Contrary to their name, fecal coliform bacteria are not limited to fecal sources, but also are commonly found in pulp and paper-mill effluents, textile processing-plant effluents, and other industrial wastewaters (Dufour 1976).

Total coliforms include a general group of bacteria, encompassing *E. coli*, fecal coliforms, as well as common soil microorganisms. States adopt water-quality standards based upon U.S. Environmental Protection Agency (USEPA) guidelines. As detection methods for microorganisms evolve, so do the USEPA guidelines. Currently, Georgia standards are based on amended statutes set forth after the USEPA 1996 Final Rule on coliform sampling, but have not officially transitioned to the recommended *E. coli* standard for drinking and recreational waters.

Data from this study indicate that water quality throughout the Catfish Pond subwatershed is adversely affected each time there is an appreciable rain event (>30mm rainfall / 24 hrs). Whitehall Experimental Forest, formerly Whitehall Plantation, was used extensively for cotton cultivation during the nineteenth and twentieth centuries. Poor land management resulted in massive soil, and though forested and relatively stable, subwatersheds on Whitehall Forest bear the scars of that era.

Present land use, such as the deepen animal confining operation, slowly eroding railroad cut, and new construction also contribute to continued watershed degradation. Poor land maintenance, steep slopes, and over 1200mm of annual precipitation combine to form erosive rills and gullies that short-circuit a healthy second-generation forest, reduce transport time of contaminants, and result in nearly instantaneous loading of receiving water bodies.

Under natural conditions, a 30–100 m forested riparian buffer such as found at the Whitehall test site would effectively filter and sequester nearly 100% of transported sediment and bacteria (Coyne et al. 1998). Hagedorn et al. (1999) reported on a method to test the efficacy of Best Management Practices (BMPs) using antibiotic resistance in *Fecal streptococcus*, a component method in the Bacteria Source Tracking (BST) toolbox (*see also* Bernhard and Field 2000; Hartel et al. 1999; Wiggins 1996). Hagedorn reported up to 95% improvement in BMP efficiency, with up to 98% certainty on bacteria host source origin. Clearly, the BST toolbox holds great promise in reducing in-stream bacteria loading, and should be refined and expanded to incorporate other methodologies.

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